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Development of cooking sector in rural areas in India—A review

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Abstract: Energy for cooking is a major concern of consumers and policy makers in India. Most of the cooking in rural India is done using biomass. Traditional biomass stoves cause significant greenhouse gas (GHG) emissions due to formation of products of incomplete combustion. As far as urban population is concerned, around 95% of the population has access to LPG as cooking fuel at subsidized rates. To increase accessibility of LPG to rural areas is economically incompetent option when compared with the solar and biogas as other options available in rural areas.

In this paper, an effort has been made to review the developments occurred in cooking sector rural areas in Indian context. The work carried out on different cooking fuels and cook stoves has been presented in order to use renewable energy sources and to identify the barriers of their dissemination. The status of cooking sector in India and the initiatives taken by the government of India has also been discussed and presented in the paper. It has been observed that the government of India is running several programs for the promotion of solar and biogas as cooking fuels in rural areas and it has succeeded to an extent.

Contents

1. Introduction

Cooking sector is considered as one of the major energy consuming sector in developing countries. As cooking is an important daily household activity, it consumes significant amount of energy and

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human effort. It is easier for people living in urban areas as the availability of resources made cooking a clean and effortless exercise. But in rural areas, particularly in developing countries, cooking is a mammoth of a task. Even with the advent of technologies in this area, people are still dependent on traditional methods of cooking. These traditional methods are not only inefficient but also cause indoor pollution. In India, a large number of rural households are still dependent on bio-fuels for cooking purpose. According to 2001 census, about 82% of rural Indian population rely primarily on unprocessed solid fuels—firewood, cow dung and crop residue [1].

Indoor air pollution remains a noteworthy global health menace that needs to be addressed. The literature indicates that ambient air pollution levels and personal exposure levels from cooking with traditional fuels are severely high. Cooking with traditional solid fuels on open flames or traditional cooking stoves may result in exposure to extremely damaging toxic pollutants. Moreover, incomplete combustion leads to the release of small particles and other constituents that have shown to be damaging to human health in the household environment. Further, it is estimated that there are nearly 2.44 million deaths attributable to biomass indoor particle air pollution in developing countries [2]. These may be due to the improper ventilation and incomplete combustion of biomass and other fuels used to meet residential cooking needs. The share of clean fuels is still a far away thing. Although solar and biogas energy technologies are quite mature technologies, their applications are still very limited.

The lack of access to clean cooking fuels and efficient technologies represent a severe bottleneck holding back progress of a nation. Improved cooking systems can alleviate these bottlenecks and put the nation forward on the path of development. In India, a lot of research has been going on in this sector. People are working to popularize the clean energy and efficient systems in cooking sector.

In this paper, the research and development of the technologies involved in cooking in India has been reviewed. An attempt has been made to study conventional as well as renewable energy based cook stoves on the basis of their financial, performance-based and environmental aspects. The endeavors of Government of India (GoI) in this regard have also been discussed. It is expected that this attempt would be useful for planners, researchers and policy makers to further improve the cooking conditions and may be able to increase the penetration of cleaner fuels in cooking sector.

2. Cooking fuel

A wide variety of resources are being used as fuels for cooking. These include fuel wood, kerosene, Liquefied Petroleum Gas (LPG), electricity, biogas, biomass and solar energy. In addition, Ramanathan and Ganesh [3] considered coal, soft coke, lignite, natural gas, charcoal as other cooking energy sources. The income of the household is the main determinant of the selection of fuel for cooking. The other factors that contribute to the fuel selection for cooking are fuel availability, seasonal income variation and power relations within household [4]. It was also concluded in [5] that the energy transition is only possible in case of the availability of the alternatives and that is why the transitions are there in urban and sub-urban areas only. Table 1 gives the share of households using particular fuel for cooking [6].

It is self evident that the major portion of cooking needs are supplied through fuel wood as fuel in rural areas. Secondly, the penetration of clean fuel for cooking purposes is almost negligible in rural areas. In India, traditional solid biofuel is still widely used for meeting cooking and space conditioning needs. Solid biofuel has traditionally been used in rural areas as cooking fuel, particularly by poor [7].

According to the National Sample Survey (NSS) data (64th round of the year 2007–08), the primary source of cooking in rural India is fire wood followed by LPG. In the year 2007–08, 77.6% of India's 159 million rural households used firewood/chips while 9.1% used LPG. Dung cakes and kerosene is used by 7.4% and 0.6% of households respectively. In stark contrast, the primary cooking fuel in urban India is LPG with 62% of India's 63 million urban households using it as primary cooking fuel. Firewood and kerosene is used by 20% and 8% of urban households respectively as primary cooking fuel. 1% of urban population use dung cake as primary cooking fuel. The overall trend in the last decade in primary energy consumption for cooking in rural areas exhibits that the number of households using firewood as primary cooking fuel is increasing steadily, while there is no significant transition with regards to LPG. As projected by planning commission, fuel wood will hold the maximum share in 2031–32 [8]. Current and expected future energy consumption in households is given in Table 2.

LPG and kerosene are currently being projected as alternatives to solid unprocessed biomass due to improved thermal efficiency of 60% in comparison to 15% of biomass based devices. The number of households using kerosene as primary cooking fuel is decreasing steadily in both urban and rural areas in the reference period (2001–02 to 2007–08).

Table 2
Current and expected future energy consumption in households [8].

Source	Consumption 2003–04 MTOE (%)	Consumption	Projections 2031–32 MTOE (%)
Fuel wood	92.57 (57.82)	205.71(MT)	106.39 (37.44)
Agro waste	17.12 (10.69)	57.1 (MT)	–
Dung cake	22.62 (14.13)	107.7 (MT)	40.47 (14.24)
Biogas	0.71 (0.44)	1.51 (million m^3)	–
Kerosene	10.69 (6.68)		15.12 (5.32)
Electricity	7.72 (4.82)		69.72 (24.53)
LPG	8.68 (5.42)		52.49 (18.47)
Total	160.11		284.19

Table 1
Percentage share of households using particular fuel for cooking (1999–2000) [6].

Income class (Rs/month)	Fuel Wood	LPG	Dung	Kerosene	Coal	Biogas	Electricity	Others	Total
Rural households									
Low income	29.24	0.16	3.85	0.24	0.61	0.01	0.00	1.37	35.5
Middle income	39.36	2.14	5.59	1.35	0.72	0.15	0.04	1.66	51.0
High income	6.95	3.10	1.18	1.12	0.23	0.16	0.04	0.73	13.5
Total	75.54	5.40	10.62	2.71	1.56	0.32	0.08	3.77	100.0
Urban households									
Low income	15.24	5.04	1.26	7.13	2.08	0.01	0.08	1.92	32.8
Middle Income	6.81	28.16	0.76	13.11	2.07	0.04	0.25	1.98	53.2
High income	0.25	11.01	0.04	1.50	0.10	0.00	0.08	1.09	14.1
Total	22.29	44.21	2.06	21.74	4.25	0.05	0.40	4.99	100.0

Government endeavors have had limited success as LPG penetration in rural India is limited with only economically affluent rural households [9]. In spite of government efforts, past trend of LPG penetration in rural areas in the same reference period indicates a mere 1% increase in terms of percentage of households (as compared to 12% increase in urban areas in same reference period) utilizing LPG as primary cooking fuel. In spite of subsidized prices in India, high up-front costs associated with the equipment needed to use LPG (stoves and cylinders) and lack of supply security have acted as a hindrance to its wider adoption among rural households [10].

Further, low population density, poor road infrastructure and low economies of scale in rural areas pose challenges to commercial viability of LPG distribution network at current prices. It can be safely assumed that additional government support for further subsidizing LPG/kerosene to enable 149 million rural households, currently dependent on biofuel, to switch over is neither economically feasible nor desirable from an energy security perspective in the long run. Hence, considered in its entirety, the adoption of LPG or kerosene based cooking as an alternative to biomass-fueled cooking on a mass scale is not feasible in the foreseeable future.

It is therefore widely believed that dependence of the population on unprocessed solid bio-fuels is expected to not only continue but also increase (to keep pace with India's burgeoning population) in the foreseeable.

As per a study by the International Energy Agency (IEA), 585 million Indians were dependent on biomass for cooking and heating in 2000 and this is projected to increase to 632 million by 2030 [11]. Dependence on biomass is expected to continue in India, due to the projected increase in rural population in absolute terms and continued lack of access to commercial fuels in rural areas particularly for cooking.

3. Cook stoves

Conventional stoves waste a lot of energy and pose many pollution hazards. Most traditional stoves can utilize only 2–10% of the energy generated by the fuel. Because of growing gap between availability and demand for firewood, scarcity of fossil fuels, poor thermal performance and pollution caused by traditional stoves, the technologists focused their attention on improving the thermal efficiencies of these stoves and also to develop more efficient, smokeless stoves. Conceptually, conventional stoves can be improved in three ways: (i) increasing thermal efficiency, (ii) reducing specific emissions and (iii) increasing ventilation. Researchers have designed various models by incorporating various components, like tunnels, baffles, dampers, grate and chimney.

In earlier cook stove models, the efforts were made to improve heat transfer efficiency via an enclosed combustion chamber and enhanced contact between hot gases and the cooking vessel.

The two features which were the most complained of or rejected by the users were—the tunnel baffle and the door damper. The cook stoves are generally made up of mud, mud brick, ceramics or metal and/or combination of these. The research work carried out on cook stoves can be looked into via three categories that are, the financial analysis, the environmental analysis and the performance analysis.

3.1. Financial aspects

In this section, people had worked upon the economical benefits through fuel saving or through efficiency enhancement of the cook stoves. Rubab and Kandpal [12] considered different factors influencing the cost and performed an economic analysis for a portable cook-stove. Hyman [13] performed an economic analysis and concluded that the expenditure on fuel can be reduced by at least 25% by using improved cook stove in place of traditional stove despite the higher cost of improved cook stove. Quadir and Kandpal [14] calculated the net annual benefits by replacing traditional cook stoves with improved cook stove and obtained the expression as

$$\mathrm{C} = (365 \times E \times C_f/H_f \times nt)(x/(100+x)) - [C_i(\mathrm{CRF}_i + f_2) - C_t(\mathrm{CRF}_t + f_1)] \quad (1)$$

where, E is the thermal energy demand for household cooking in MJ/day, C_f is the price per unit amount of fuel saved. The expression $[x/(100+x)]$ represents the fraction of the earlier expenditure saved by the use of cook stove where x is the percentage improvement in the efficiency of fuel utilization. The expression $[C_i(\mathrm{CRF}_i+f_2)-Ct(\mathrm{CRF}_t+f_1)]$ is the incremental annual cost of replacing the traditional cook stove with the improved cook stove. Here, C_i and C_t represents the capital cost of improved and traditional cook stove respectively. CRF_i and CRF_t is the capital recovery factor for improved and traditional cook stove respectively. f_1 and f_2 are the fraction of capital cost used in operation and maintenance of traditional cook stove and improves cook stove respectively.

Kauntia [15] developed a multi-fuel and biomass cook stove and derived a saving of 40–50% of fuel saving. Alam and Chowdhury [16] presented an improved earthen cook stove with two cooking stations and a chimney to reduce the fuel consumption rate. They evaluated economic achievements of the improved cook stove. Champier et al. [17,18] presented the case of electric power generation from biomass cook stove and further extended their work to obtain the optimum mechanical design of the thermo-electric (TE) generator. They found that the output power obtained for the end users is economically comparable with solar panels. Shrimali et al. [19] presented the business view point in the dissemination of improved cook stove in India. They considered six elements, that is, design, customers targeted, financing, marketing channel strategy and organizational characteristics influence the scalability and self-sustainability of these businesses.

3.2. Performance aspects

Khummongkol et al. [20] proposed a simulated model of charcoal cook stove and developed a correlation between air velocity and temperature. Mathematically, a cook stove is governed by energy and mass balance equations. The energy balance in the stove chamber can be written as

$$dQ/dt = Q_{com} + Q_{conv\_in} - Q_{conv\_out} - Q_{rad\_gp} - Q_{rad\_ga} - Q_{sto} - Q_{cond} \quad (2)$$

where, Q_{com} is the rate of heat generated in the stove, Q_{conv_in} and Q_{conv_out} are the rates of enthalpy flow in and out of the stove, Q_{rad_gp} is the rate of heat radiated from grate to pot base, Q_{rad_ga} is the rate of heat radiated from grate to ash floor, Q_{sto} and Q_{cond} are the heats of accumulation and conduction, that is, the heat stored in the wall during cooking and flow through the wall during cooking.

Natarajan et al. [21] compared the efficiency of kerosene stove with that of a conventional stove. They made an attempt to use waste vegetable oil as fuel by making certain modifications in kerosene stove. They observed the efficiency of stove with vegetable oil as fuel to be as high as 48.9%. Jetter and Kariher [22] tested different combinations of cook stoves and fuels for their performance. They found that cook stoves with smaller mass components exposed to the heat of fuel combustion tended to take lesser time to boil, have better fuel efficiency. Miah et al. [23] figured out the social, economic and environmental consequences

of wood fuel usage in the traditional cooking stove. They conducted a study to determine the structural characteristics of the traditional cooking stoves, amount of wood fuel consumed in the rural floodplain areas in Bangladesh. In two parts, Agenbroad et al. [24,25] developed a simple model for understanding the operating behavior of natural convection biomass cooking stoves. Pine et al. [26] performed a longitudinal analysis of adoption patterns and intensity of use of a Patsari improved biomass cook stove. The analysis was performed on randomly selected households of a community of Michoacan, Mexico. Multinomial logistic regression was used to develop a model of household and community characteristics associated with early adoption of the Patsari, leading to the development of bi-level model for targeting improved stove dissemination efforts.

3.3. Environmental aspects

Kauntia [15] developed a multi-fuel and biomass cook stove and found that it was less air polluting. It was also concluded that improved cook stoves emits less health damaging pollutants and greenhouse gases and achieves higher efficiency [27]. Further, changing from unprocessed fuel to coal briquettes result in the reduction of 85% of Total Suspended Particulates (TSP), 77% of Carbon Monoxide (CO), 53% of Global Warming Commitment (GWC) on a geometric mean basis as a result of 80% reduction in Products of Incomplete Combustion (PIC). MacCarty et al. [28] performed an experimental study of five different types of biomass cook stoves. They showed that for sustainable harvesting situations, some improved cook stoves with rocket type combustion or fan assistance can reduce overall warming impact from PICs by as much as 50–95%. Yuntenwi et al. [29] analyzed the effect of moisture contents of wood on the performance and emissions of three different types of biomass based cook stoves. They concluded that an increase in moisture content increases the efficiency up to a certain point. Jetter and Kariher [22] also found that different combinations of cook stoves are less polluting. MacCarty et al. [30] tested fifty cooking stoves in the laboratory to compare the fuel use, CO and particulate matter (PM) emissions produced. They categorized the stoves under seven categories: simple stoves without combustion chambers, stoves with rocket type combustion chambers, gasifier stoves, fan-assisted stoves, charcoal burning stoves, liquid/gas fuel stoves and wood burning stoves with chimneys. The authors recommended benchmarks of improved cook stove performance. Alam and Chowdhury [16] also evaluated the ecological and socio-cultural achievements of the improved cook stove. Bhattacharya and Salam [31] looked upon the biomass options for cooking from the point of view of greenhouse gas emissions (GHG). They figured out that traditional biomass fired cook stoves cause significant GHG emissions but modern biomass based improved stoves play an important role in mitigating the GHG emissions. Wijayatunga and Attalage [32] analyzed the household demand and the gaseous emissions due to cooking activity. It was found that the highest level of emission was recorded in rural areas.

4. Clean energy in cooking

The use of cleaner cooking fuel is impeded by four main factors as the lack of motivation and the pressure for switching over to cleaner facilities, the lack of modern energy technology options, the financial risks and the lack of financing and other support [33]. To make a transition from traditional fuel to cleaner fuel, two domains must be addressed as risk and livelihood (Fig. 1). Risk reduction would build confidence while improvement in livelihood domain would build demand. Quadir et al. [34] made a modest study to find out the barriers in the dissemination of renewable energy technology for cooking. The barriers are summarized as given in Table 3. Although this work is quite old, the barriers identified are still obstructing the path of dissemination of renewable energy technologies. The two well recognized clean energy sources in cooking sector are solar energy and biomass. A lot of research is going on technical, economical and environmental aspects of these two energy resources to enhance their penetration in the cooking sector.

4.1. Solar cookers

Globally, a lot of literature has been available on the development of solar cookers. A lot of research has been carried out on solar cookers which clearly have proven the utility of solar cooker as a renewable and pollution free energy source. The researchers, in the past, considered various designs of solar cookers to optimize their thermal performance and efficiency.

4.1.1. Economic aspects

Kumar et al. [35] performed a financial feasibility analysis of box type cooker and evaluated the annual benefits accrued in terms of the meals cooked and the fuel saved per meal. The cost per unit of useful energy delivered by a solar cooker is obtained as the ratio of the total annual cost of the solar cooker to the annual amount of useful energy delivered by it. The useful energy delivered annually by a solar cooker may be estimated by multiplying the total number of meals cooked by the solar cooker with the useful energy required to cook a single meal. The C_{pu} may be

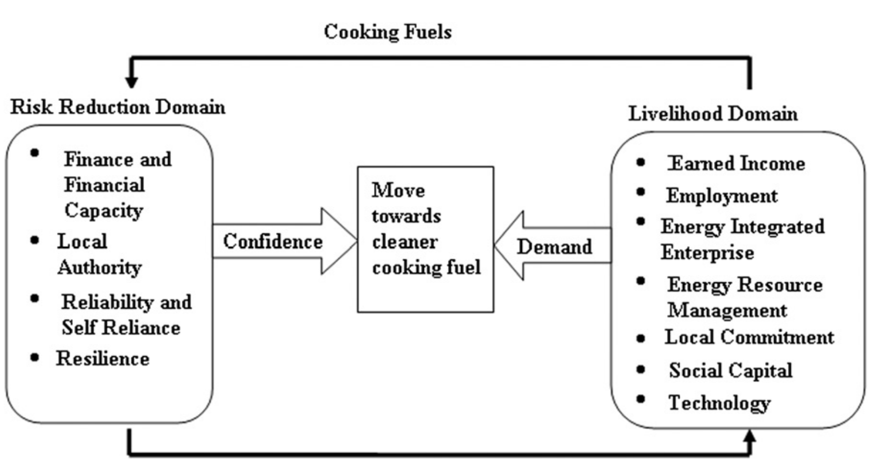

Fig. 1. Potential contribution of the dual domain [33].

Table 3
Barriers in the dissemination of renewable energy technologies [34].

Economical	Technological	Institutional	Socio-cultural
High investment cost	Immature technology	Difficulties in obtaining loan from government	Lack of perceived needs
Long payback period	Inappropriate technology	Lack of coordination among different agencies	Unwillingness to adjust to the changes in life style
Lack of purchasing power			
Poor reliability and uncertainty about benefits			
Lack of infrastructure			
Incompatibility with existing work organization			
Alternative fuels available with zero private cost	Lack of governmental support	Prioritization differences between decision makers and users in the family	
Requirement of skilled Manpower			
	Unavailability of adequate manpower to develop, install, operate and maintain technology	Poor technology transfer	Difficulty in integration with social structure
			Disharmony with prevailing values and ideology

calculated by dividing C_{meal} by the amount of useful energy, E_s, required to cook a single meal,

$$C_{pu} = C_{meal}/E_s \tag{3}$$

The amount of useful energy to cook a single meal may be obtained by

$$E_S = \sum_{c=1}^{n_1} m_c s_c (T_b - T_a) + \sum_{d=1}^{n_2} m_d E_d + m_w L \tag{4}$$

where, $c=1$ to n_1 represents different food items included in the meal, m_c is the mass of c^{th} item, s_c is the specific heat of c^{th} item, T_b is the boiling point, T_a is the ambient temperature, E_d is the specific energy required for chemical change in d^{th} food item, m_w is the mass of water evaporated and L is the latent heat of vaporization of water.

For different sizes and masses of components and market prices, the following relation between capital cost (C_{cap}) and aperture area (A) has been developed as [35]

$$C_{cap} = (f+1)\left[\sum_{i=1}^{3} (a_{1i}\rho_i t_i A^{b_i}) C_{mi} + \sum_{j=1}^{3} (a_{2j} A) C_{mj}\right] \tag{5}$$

where, $i=1,2,3$ represents enclosure, absorber tray and glass wool padding respectively; $j=1,2,3$ refers to mirror and two glazings respectively; a_{1i}, b_i and a_{2j} are regression coefficients. The thickness (m), density (kg/m^3) and market price (Rs/kg) of the i^{th} component are represented by t_i, ρ_i and C_{mi} respectively; C_{mj} is the market price (Rs/m^2) of the j^{th} component; f is a fraction and represents the proportion of total cost which includes costs of labor and miscellaneous items such as pots, strips,gasket, hinges, rivets, etc.

Nahar [36–38] had also presented some simple designs of solar cookers for boiling animal feed with the help of locally available materials. An ultra low cost design was designed by Beaumont et al. [39]. It was designed with minimal tools, skills or special materials. It consisted of a shallow 1 m^2 hole in the ground, insulated with straw and lined with adobe (mud and straw), a glass or plastic roof, and a 1 m^2 aluminized plastic reflector with guy ropes for adjustment. An insulated fabric door allows access to the oven; pots are slid in, onto a metal base plate. The cooker has been shown to provide cooked food for 10–12 people on clear days with meals around midday and dusk (assuming 0.4 kg dry weight of food per person daily). Nandwani [40] designed a hybrid food processor based on solar energy to carry out cooking, heating/pasteurizing water, distillation of small quantity of water and drying domestic products.

4.1.2. Performance aspects

Tabor [41] and Narshimha Rao et al. [42–44] recommended the use of mirrors as booster of solar energy. A FORTRAN program was developed by Narsimha Rao et al. [45] for assessing the contribution of booster mirrors in different orientation and tracking modes. Habeebullah et al. [46] developed a solar cooker surrounded by four mirror reflectors. Mirdha and Dhariwal [47] compared the thermal performance of a solar cooker with a booster mirror fixed on a south facing window with that of a conventional solar cooker. Dang [48] explained the heat collection increases with the help of boosters. The symmetric booster mirrors produce a concentration ratio of 2.0.

Algifri and Towai [49] discussed a method to find out a reflector performance factor and an orientation factor that depends upon the elevation of the sun, solar surface azimuth angle and the reflector tilt angle. Pande and Thanvi [50] designed a solar cooker with inner box in step fashion and the cooker was fixed on a flexible iron stand to keep the system at optimum tilt in different seasons. Shrestha [51] in his work suggested one glass cover with selective coating on absorbing tray is much better than two glass glazing with a simple black coated absorber tray. Tripanagnostopoulos and Nousia [52] performed an analysis with various color selective coatings on absorber tray.

Amer [53] found that double exposure to cooker from top as well as bottom reduced cooking time to about 30–60 min when compared with solar cookers. Recently, Harmin et al. [54] performed an experimental analysis with finned absorber plates. Other design modifications include, double exposure cooker carrying a specially designed cooking pot with fins on the outer joint by Harmin et al. [55], concave shape of lid of utensil rather than flat shape as suggested by Gaur et al. [56] and cylindrical central cavity in cooking vessel by Reddy et al. [57].

Further, Tiwari and Yadav [58] modified the design by making the base of the oven to act as lid thereby reducing the convective heat transfer losses. As a modification, Khalifa et al. [59] simulated a cooker and permitted heating from the bottom and sides. They found that this new cooker took lesser time to cook as compared with conventional cooker. Nahar [60–63] worked for multipurpose designs of solar cooker, that is, solar cooker cum solar water heating system. He carried out the performance

analysis and calculated efficiency. The efficiency calculations were also performed after making certain modifications in the design. He reported an overall efficiency of this improved cooker as 24.6%. Scharzer et al. [64] have classified the solar cookers into four categories and carried out a performance analysis. Malhotra et al. [65] found that reduced volume of cooking chamber results in a good temperature rise and thereby, reducing cooking time. Grupp et al. [66] presented an advanced solar cooker by making a fixed cooking vessel directly attached with the absorber plate. Khalifa et al. [67] took vapor tight cooking pot thermally bonded to a single glazed collector plate and achieved the water boiling time as 24 min-m^2/kg. The efficiency was found to be 27%.

4.2. Biogas

Biogas is another renewable energy source used for cooking purposes. Biogas contains 50–70% of methane and 30–50% of carbon dioxide depending on the substrate as well as small amount of other gases including hydrogen sulfide [68]. Methane is the component chiefly responsible for a typical calorific value of 21–24 MJ/m^3 or around 6 kWh/m^3 [69]. Methane is produced by the biochemical reactions occurring in the presence of three bacterias. Firstly, during hydrolysis, extracellular enzymes degrade complex carbohydrates, proteins and lipids into their constituent units. Next is acidogenesis (or fermentation) where hydrolysis products are converted to acetic acid, hydrogen and carbon dioxide. The facultative bacteria mediating these reactions exhaust residual oxygen in the digester, thus producing suitable conditions for the final step: methanogensis, where obligate anaerobic bacteria control methane production from acidogenesis products [70].

In developing countries, cookers/stoves, lamps and engines are appliances commonly fueled by biogas. There are two basic designs of biogas plants that are popular in India. These are

(i) Floating drum type plants: This design was developed and popularized by the Khadi & Village Industry Commission (KVIC) of India and, hence, is known as the KVIC model [71,72]. These were standardized in 1962 and are used widely even now. These plants have an underground well shaped digester having inlet and outlet connections through pipes located at its bottom on either side of a partition wall. An inverted drum (gas holder), made of mild steel, is placed in the digester, which rests on the wedge shaped support and the guide frame at the level of the partition wall. This drum can move up and down along a guide pipe with the accumulation and disposal of gas, respectively. The weight of the drum applies pressure on the gas to make it flow through the pipeline to the point of use.

(ii) Fixed dome type plants: In spite of the increasing popularity and acceptance of the KVIC model, it is, by and large, beyond the reach of most of the rural people because of its high installation cost, particularly of the fixed steel drum. So, there was an apparent need to have an alternative inexpensive design to bring it within the reach of the poor rural population. Because of these reasons, the fixed dome type models of biogas plant have come into place. These are

(a) Janta biogas plant
(b) Deenbandhu biogas plant

(a) Janta model of biogas plant: This is the first fixed dome biogas plant that was introduced in 1978. The main feature of this model is that the digester and the gas holder are integrated parts of the brick masonary structure. The digester is made of a shallow well having a dome shaped roof on it. The inlet and outlet chambers are connected with the digester through large chutes. These chambers are above the level of the junction of the dome and the cylindrical well. The gas pipe is fitted on the crown of the masonary dome.

(b) Deenbandhu model of biogas plant: The Deenbandhu model was developed by Action for Food Production (AFPRO), New Delhi, India, in 1984. The word deenbandhu means friend of the poor. Until now, this model is the cheapest among all the available models of biogas plant. This model is designed on the basis of the principal of minimization of the surface area of a biogas plant to reduce its installation cost without sacrificing the functional efficiency [73]. The design consists of two spheres of different diameters, joined at their bases. The structure thus formed acts as the digester or fermentation chamber, as well as the gas storage chamber. The digester is connected with the inlet pipe and outlet tank. The upper part above the normal slurry level of the outlet tank is designed to accommodate the slurry to be displaced from the digester with the generation and accumulation of biogas.

4.2.1. Economic aspects

The economics involved in the plant has been discussed by many researchers. Kandpal et al. [74,75] discussed the economics of family sized biogas plant in India. A generalized cost function of capital cost of a biogas plant has been obtained as

$$C = C_o[a + b(V/Vo)] \tag{6}$$

where, C is the capital cost (Rs) for a biogas plant of capacity V and a and b are constants, values of which depend on the capacity, Vo of the reference biogas plant with the capital cost of C_o. The total annual operation and maintenance cost, C_{OM}, for a plant of capacity V and capital cost C is given by [74]

$$C_{OM} = 365VW_{CW}C_D + 0.04C \tag{7}$$

where, W_{CW} is the weight of dung required to produce 1 m^3 of gas (kg) and C_D is the price of fresh dung (Rs/kg).

Singh and Sooch [76] presented a comparative study based on economics of different models of biogas plants. Garfi et al. [77] presented the technical, environmental and socio-economic impacts of low cost tubular digesters in rural communities of Peruvian Andes.

4.2.2. Performance aspects

People have discussed different biomass feed stocks that can be converted into biogas. Some of the examples include water hyacinth as discussed by Srivastava et al. [78], kitchen wastes as discussed by Kale [79], crop residues such as rice straw discussed by Andersson and Bjornsson [80], terrestrial weeds by Das and Ghatnekar [81] and by Kalia and Kanwar [82] and aquatic weeds by Sharma et al. [83]. Chanakya et al. [84] presented their field experiences with leaf litter based biogas plants. The problem with biogas is its storage as it contains a good percentage of carbon dioxide in it. It can only be stored and transported when it can be compressed and filled in cylinders. This is possible only after removing its CO_2, H_2S and water vapour components. Kapdi et al. [85] studied the biogas scrubbing, compression and storage prospects in Indian context.

5. Indian scenario

India is blessed with an abundance of human capital whose potential is not fully realized especially in rural areas. Among other things, access to reliable energy is vital to ensuring that these communities move beyond subsistence and contribute to the country's economy. Thus, energy is the key driver to lift people out of poverty and provide them with a better quality of

living. Consequently, provisioning of energy services in the rural areas is a priority for the GoI.

About 70 percent of India's population currently lives in rural areas but access to and availability of reliable and assured energy to them is far from satisfactory. In the electricity sector, over 44.2% (84 million households) still have no access to electricity. Similarly, in the household cooking sector an overwhelming proportion of the rural population continue to burn traditional biomass fuels in an inefficient manner. Fuel wood, chips and dung cakes, contribute around 30% of the primary energy consumed. Meanwhile, the penetration of petroleum fuels for lighting and cooking has been low in the rural areas. Despite large national level subsidies, only 5.4% and 1.62% of the rural households were using LPG and kerosene, respectively, as fuel for cooking, though kerosene is used by 55% of the rural households for lighting [86]. Ravindranath and Ramakrishna [87] and Ravindranath and Gupta [88] in their studies analyzed the viability and financial feasibility of different cooking options for cooking in India. Later, Agrawal and Singh [89] presented a fuzzy multi-objective analysis for the optimum allocation of energy resources for cooking in the households of Uttar Pradesh, India. LPG, biogas and fuel wood were found to be the most favorable resources. Solar thermal lagged because of its cost. Purohit et al. [90] presented a methodology to estimate the potential of renewable energy technologies for domestic cooking in India.

5.1. *Efforts and initiatives on rural cooking energy*

In the rural cooking energy sector efforts have been ongoing for over three decades. GoI initiated several programmes and schemes for the dissemination of clean and efficient technologies for cooking and other thermal applications. Some of the programmes are listed below:

5.1.1. *National Biogas and Manure Management Programme (NBMMP)*

NBMMP is being implemented in the country since 1981–82 for promotion of biogas plants based on cattle dung and other organic wastes. The NBMMP mainly caters to setting up of family type biogas plants for meeting the cooking energy needs in rural areas of the country along with making enriched bio-fertilizer availability to farmers. With the installation of 4.31 million family type biogas plants by January 2011, about 35% of the estimated potential has been realized so far. Installation of 1,19,914 family type biogas plants during the year 2009–10 is likely to result in the estimated annual saving of about 0.305 million tonnes of fuel wood equivalent and production of about 11.57 million kg of urea equivalent or 2.147 million tonnes of organic manure per year. In addition, the rural families would benefit in terms of reducing drudgery of women involved in collecting fuel wood from long distances and minimizing health hazards during cooking in smoky kitchens. It is estimated that the construction of 1,19,914 biogas plants would have generated about 3.35 million person-days of employment for skilled and unskilled workers in rural areas during the year.

5.1.2. *National Programme on Improved Cookstoves (NPIC)*

The National Programme on Improved Cook stoves (NPIC) was started by the Ministry of Non-conventional Energy Sources (MNES), Government of India, in 1985 to achieve the twin objectives of fuel wood conservation and smoke reduction in kitchens. The general and technical features of some of the models recommended by the NPIC are given in Table 4 [91]. NPIC has overseen the installation of 28 million improved cook stoves, saving nearly 20 million tons of firewood per year [92].

5.1.3. *National Biomass Cook Stove Initiatives*

The Ministry of New and Renewable Energy (MNRE), Government of India on 2nd December 2009 launched National Biomass Cook stoves Initiative (NBCI) at New Delhi with the primary aim to enhance the availability of clean and efficient energy for the energy deficient and poorer sections of the country. The initiative emphasizes on enhancement of technical capacity in the country by setting up state-of-the-art testing, certification and monitoring facilities and strengthening R&D programmes in key technical institutions [93].

5.1.4. *Jawaharlal Nehru National Solar Mission*

The main objective of JNNSM is to promote off-grid applications of solar energy (both SPV and Solar Thermal). Various off-grid solar photo voltaic systems/applications up to a maximum capacity of 100 kWp per site and off-grid and decentralized solar thermal applications, to meet/supplement lighting, electricity/power, heating and cooling energy requirements would be eligible for being covered under the Scheme. For mini-grids for rural electrification, applications up to a maximum capacity of 250 kW per site would be supported [94].

As regard off-grid solar thermal systems, a total of around 0.5 million m^2 of collector area has been installed during the year till December, 2010 in addition to different solar air heating and steam generating systems. As per the studies undertaken through UNDP/GEF Global Solar Water Heating India Project, being implemented by the Ministry, five States, namely, Karnataka, Maharashtra, Tamil Nadu, Andhra Pradesh and Gujarat account for 67% of the potential. A total of 11 districts with large potential have been identified as Bengaluru, Pune, NCR, Thane, Hyderabad, Nagpur, Kolkata, Chennai, Coimbatore, Ahmedabad and Jaipur [95].

As per the annual report of MNRE, a summary of the targets and the achievements are given in Table 5·[96]. On the other side, the

Table 4
Different Cook stoves and their specifications.

S.no.	Model name and year developed	Normal cooking hours (minutes)	Power output (kW)	Burning rate (kg/h)	Thermal efficiency
1.	Abhinav	40–60	0.98	1.0	22.0
2.	Akash	40–60	1.15	1.0	21.9
3.	Alok	60–80	1.77	1.5	26.3
4.	Aravali-U	40–60	1.3	1.5	25.3
5.	Astra	35–55	1.34	1.0	30.0
6.	Bhagyalaxmi	40–60	1.25	1.0	26.0
7.	Dengli	40–60	0.98	1.0	25.0
8.	Doachhi	60–80	0.90	1.0	20.2
9.	Gaurav	40–50	1.89	1.5	28.1
10.	Grihlaxmi	50–70	1.10	1.0	28.8
11.	Harsha	60–80	1.11	1.06	24.8
12.	Janta	40–50	2.68	1.5	50.2
13.	Kesari-200	80–120	6.64	4.0	37.1
14.	Laxmi	40–60	0.98	1.0	22.0
15.	Mamta	50–70	0.98	1.0	24.0
16.	Meghalaya	40–60	0.7	1.0	22.8
17.	Mohini-U	40–50	1.14	1.0	25.4
18.	Navjyoti	65–85	0.98	0.5	22.6
19.	Parishad-21	35–55	1.68	1.5	30.0
20.	Pawan-II	40–60	1.07	1.0	22.0
21.	Priagni	55–75	1.16	1.01	26.0
22.	Priya	50–70	0.98	1.0	20.0
23.	Sohini	60–80	0.80	1.5	24.3
24.	Sudha	30–40	1.92	0.97	42.8
25.	Sugam-II	40–60	1.18	1.0	28.2
26.	Sugma Seva	45–60	1.12	1.0	25.1
27.	Sukhad	40–60	1.0	1.0	25.0
28.	Surbhi-T	40–60	1.16	1.0	30.4
29.	Udai	45–75	0.9	1.0	20.0

Table 5
Programme wise physical target and achievement made during 10th five year plan [96].

Name of the scheme/project/ programme	Units	2002–03		2003–04		2004–05		2005–06		2006–07		Xth Plan	
		T[a]	A[b]	T	A	T	A	T	A	T	A	T	A
Biogas plants	No. in Millions	0.153	0.153	0.149	0.141	0.1	0.109	0.066	0.061	0.1	0.096	0.568	0.560
Solar cooker	× 1000 nos.	35	10	35	5	35	20	35	19.769	22	16.209	162	70.978
SWHS	× 1000 m^2 collector area	50	45	55	0	100	150	400	400	400	400	1005	995

[a] Target.
[b] Achievement.

Table 6
Average expenditure share on "Clean" fuels across states [97].

State	Rural			Urban		
	1983	1993–94	1999–2000	1983	1993–94	1999–2000
Andhra Pradesh	22.3	20.8	25.2	39.8	58.7	74.4
Assam	21.8	18.5	24.6	28.9	59.2	70.3
Bihar	25.9	22.3	21.1	22.3	38.9	46.5
Gujarat	22.6	27.8	35.4	57.9	79.0	85.9
Haryana	17.7	16.3	23.9	40.2	64.2	69.7
Himachal Pradesh	9.3	13.0	27.5	51.0	80.8	88.1
Karnataka	17.8	18.1	21.8	38.7	59.8	71.8
Kerala	16.4	17.3	21.0	24.0	29.5	41.2
Madhya Pradesh	17.2	13.0	14.5	29.1	53.6	61.6
Maharashtra	21.3	29.5	36.2	65.1	83.9	88.4
Orissa	17.1	16.2	17.4	20.6	48.2	49.6
Punjab	13.0	19.6	29.5	47.8	77.2	80.8
Rajasthan	16.3	11.3	11.9	31.3	56.7	66.3
Tamil Nadu	18.2	24.1	27.7	38.7	59.9	77.1
Uttar Pradesh	16.2	16.6	18.9	28.1	52.5	60.1
West Bengal	24.5	25.6	22.4	27.8	53.3	64.6
All India	19.5	19.9	22.5	38.8	60.9	70.1

state-wise expenditure share on clean fuels is shown in Table 6 [97].

6. Conclusion

Cooking is an exercise which is performed in each of the household for at least two times a day. In order to make the cooking exercise clean, cooking fuel plays an important role. An attempt has been made to carry out a literature review on the developments of cooking sector in a developing country like India. It was found that the income of household is the main determining factor for the selection of fuel for cooking. This income disparity clearly made LPG and other cleaner fuels popular in urban and sub-urban areas leaving fuel wood and biomass as fuel options for rural areas.

Based on literature review it has been found that development of efficient cooking systems is another area for researchers as the conventional cook stoves not only cause indoor pollution but also are less efficient. It was found that certain design modifications like enclosed combustion chamber and enhanced contact between hot gases and the cooking vessel can improve the heat transfer efficiency. Besides efficiency, economics involved plays a considerable role in the dissemination of improved cook stoves in rural areas. Overall cost can be reduced by improving efficiency and thereby, saving fuel.

Renewable energy based cooking systems are found to be the best alternatives for cooking. In India, solar radiations are available for most part of the year. The solar cookers are the best option for cooking because of their negligible operating cost and subsidies on capital cost are provided by the government of India. Many schemes for setting up of biogas plants across the nation are being implemented in India.

Further, despite all round efforts, clean and efficient cooking system is still out of the reach of a considerable part of the nation and there is a need for wide publicity of the advantages of renewable energy based cooking systems as well as the health hazards of using fuel wood. Proper identification of potential users, given due consideration to the perceived needs of users, realistic assessment of resources and overcoming technological inadequacy would lead to the dissemination of renewable energy technologies in rural parts of the country.

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